

Physics-based Simulation of Human Posture Using 3D Whole Body Scanning Technology for Astronaut Space Suit Evaluation

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ABSTRACT

Over the past few years high precision three-dimensional (3D) full body laser scanners have been developed to be used as a powerful anthropometry tool for quantification of the morphology of the human body. The full body scanner can quickly extract body characteristics in non-contact fashion. It is required for the Anthropometry and Biomechanics Facility (ABF) to have capabilities for kinematics simulation of a digital human at various postures whereas the laser scanner only allows capturing a single static posture at each time.

During this summer fellowship period a theoretical study has been conducted to estimate an arbitrary posture with a series of example postures through finite element (FE) approximation and found that four-point isoparametric FE approximation would result in reasonable maximum position errors less than 5%. Subsequent pilot scan experiments demonstrated that a bead marker with a nominal size of 6 mm could be used as a marker for digitizing 3-D coordinates of anatomical landmarks for further kinematic analysis. Two sessions of human subject testing were conducted for reconstruction of an arbitrary postures from a set of example postures for each joint motion for the forearm/hand complex and the whole upper extremity.

INTRODUCTION

Three-dimensional whole body laser scanning can extract body surface and volume characteristics in seconds to construct a 'digital human' and is more repeatable than traditional anthropometry. 3D scan data from a standard pose of an astronaut can be processed to create a 3D whole body CAD model for further computer simulation. However, this digital human scanned at a single static posture may not be useful for assessment of suit accommodation and further evaluation the biomechanical requirements of a particular suited/unsuited pose or task. Thus, it requires for the ABF to have capabilities for kinematics simulation of a digital human at various postures without losing the integrity of physical parameters (such as segment lengths, widths, depths, soft tissue deformation, etc).

Current ergonomic tools only allow kinematics simulations using a standard model with anthropometric scaling, thereby lacking simulations of an individual with diverse anthropometric variations and physical features. Furthermore, the ABF has been using a stick figure model (ERGO model) written in MATLAB. The ERGO model is based on traditional anthropometric measurements and has the ability to be repositioned but lacks surface definitions (Figure 1).

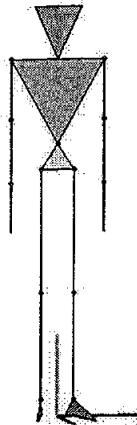


Figure 1. ERGO model in the anatomic position

WORK ACCOMPLISHED

During this summer a theoretical study has been conducted to estimate an arbitrary posture with a series of example postures through finite element (FE) approximation. Subsequent pilot experiments were conducted using a 3D whole body scanner (Human Solutions, Inc) to find optimum markers for digitizing 3D coordinates of anatomical landmarks for kinematic analysis. Two human subject testing was conducted for reconstruction of an arbitrary postures from a set of example postures for each joint motion.

FE Approximation of Arbitrary Postures

Human joint motion can be idealized as a circular arc motion with one degree of freedom (DOF) for the elbow joint or two DOF's for the wrist joint and three DOF's for the shoulder joint. First, a single DOF joint with unit distance and 90 degree range of motion (ROM) was used to approximate the arbitrary positions at an interval of 3 degrees along the ROM with three example angular positions of 0, 45, and 90 degrees (Figure 2 left). The 3-point FE approximation was conducted using an isoparametric formulation, resulting in quadratic Legendre interpolation (Logan 2002). The maximum position error was estimated to be 3%. However, the error would be substantially increased to 22% when the same 3-point FE approximation using three example angular positions of 0, 90, and 180 degrees was used to interpolate for a joint with 180 degree ROM (Figure 2 right). Higher order FE approximation could substantially reduce the maximum position error. With four example angular positions of 0, 30, 60, and 90 degrees it became 0.3% and 4.5% for 90 and 180 degree ROM's, respectively (Figure 3).

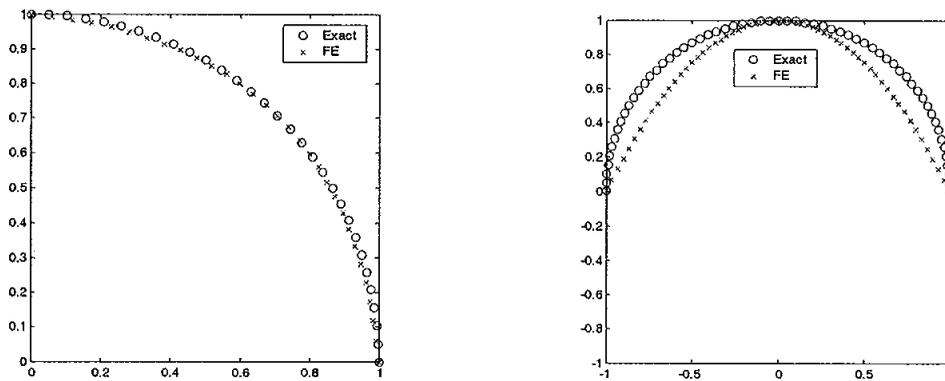


Figure 2. 3-point FE approximation of a single DOF joint with 90 and 180 degree ROM.

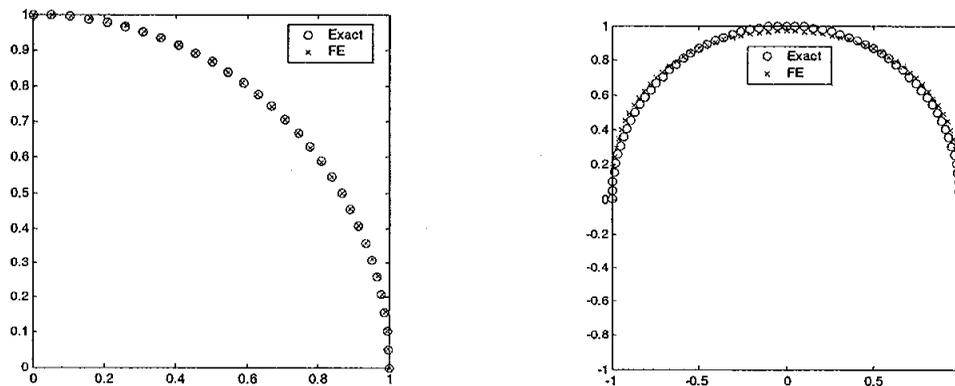


Figure 3. 4-point FE approximation of a single DOF joint with 90 and 180 degree ROM.

Similar theoretical study was conducted for a two DOF joint. The joint had unit distance and 90 and 180 degree ROM's. Both 3- and 4-point FE approximations were used for each DOF so that a total of 9 and 16 example positions were used to interpolate arbitrary positions in the joint space. The 3-point FE approximation resulted in maximum position error of 4.5% and 22.0% for 90 and 180 degree ROM, respectively (Figure 4). On the other hand, the 4-point FE approximation resulted in maximum position error of 0.5% and 4.6% for 90 and 180 degree ROM, respectively (Figure 5).

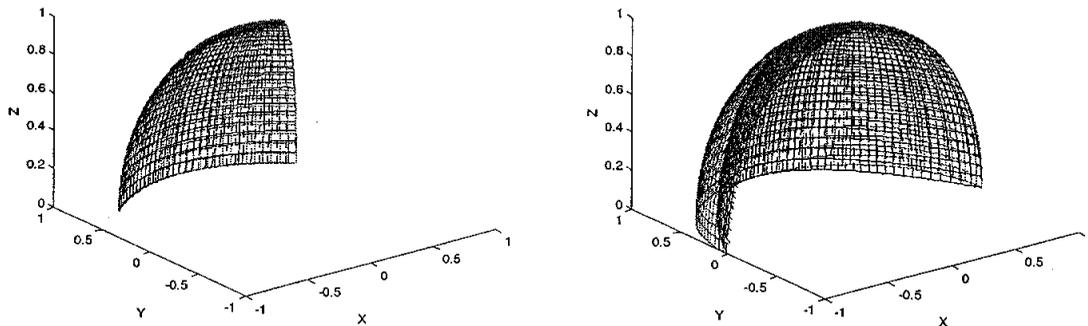


Figure 4. 3-point FE approximation of a two DOF joint with 90 and 180 degree ROM.

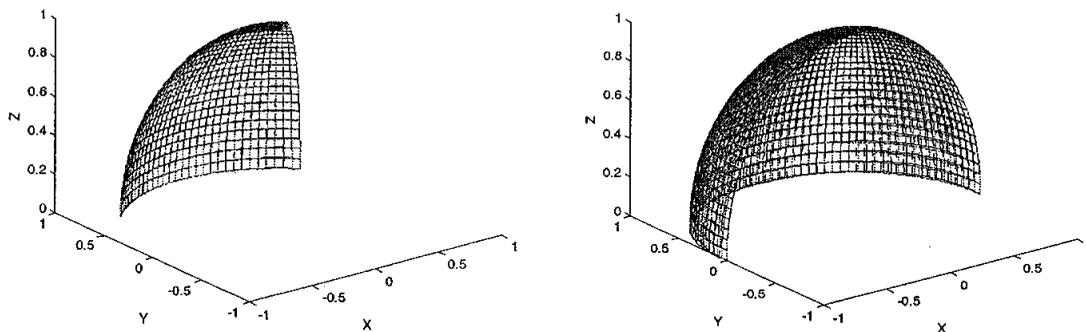


Figure 5. 4-point FE approximation of a two DOF joint with 90 and 180 degree ROM.

From these studies it was concluded that at least four example postures are needed to interpolate an arbitrary posture using FE approximation for each joint DOF. Thus subsequent experimental studies were conducted based on these results.

Scanning of the Forearm/Hand Complex and the Upper Extremity at Example Postures

After a few trial scans with various markers it was concluded that a plastic bead with a diameter of 6 mm could be captured and digitized in ScanWorX V2.8 software (Human Solutions, Inc). To test the results of the theoretical study, a 3D laser scanning study was conducted with a human subject for the motion of the forearm/hand complex (FHC) since

it has both one and two DOF joints. A total of 27 bead markers were attached on each anatomical landmark for 3D kinematic analysis of joint motion (Figure 6).

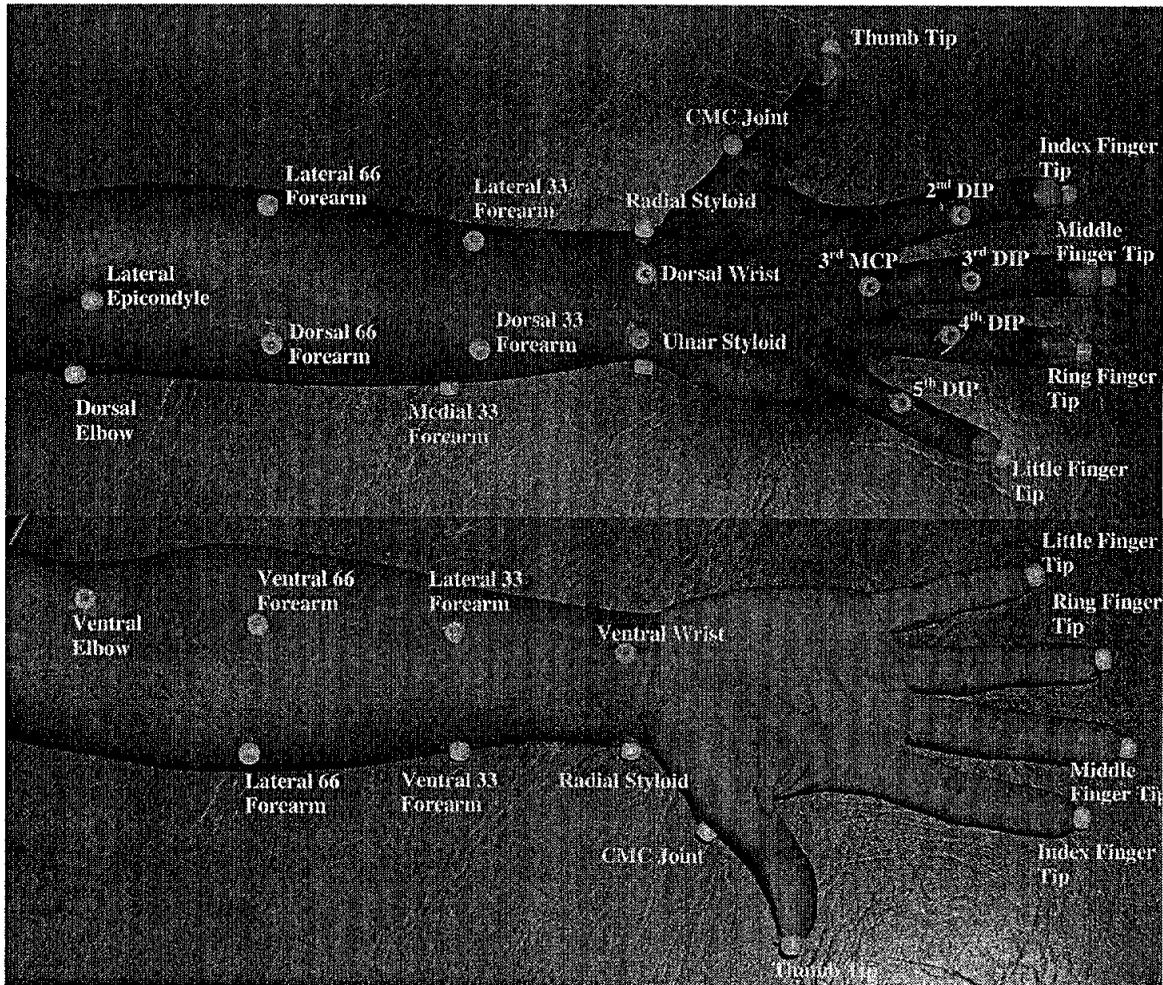


Figure 6. Bead markers on the forearm/hand complex.

The FHC with bead markers were scanned and processed using ScanX V2.8 software. The subject was in supine position with the FHC in full pronation. Then, for each joint DOF a series of four scans were made. The subject voluntarily moved each joint at zero, one-, two-thirds, and full ROM. Wrist flexion/extension, radial/ulnar deviation, forearm pronation/supination, and elbow flexion/extension pairs were scanned so that a total of 16 scans plus one anatomical neutral scan were made as example scans for FE approximation. To minimize horizontal gaps in the scan the upper extremity was maintained in vertical position as much as possible. In the viewer window with “Standard Projection”, the region of interest was selected from the whole-body scan image by removing the non-interest areas with Shift-Control and polygonal selection. Then, each of the bead markers were manually located using “persistent” markers in the Measure3D window (Figure 7).

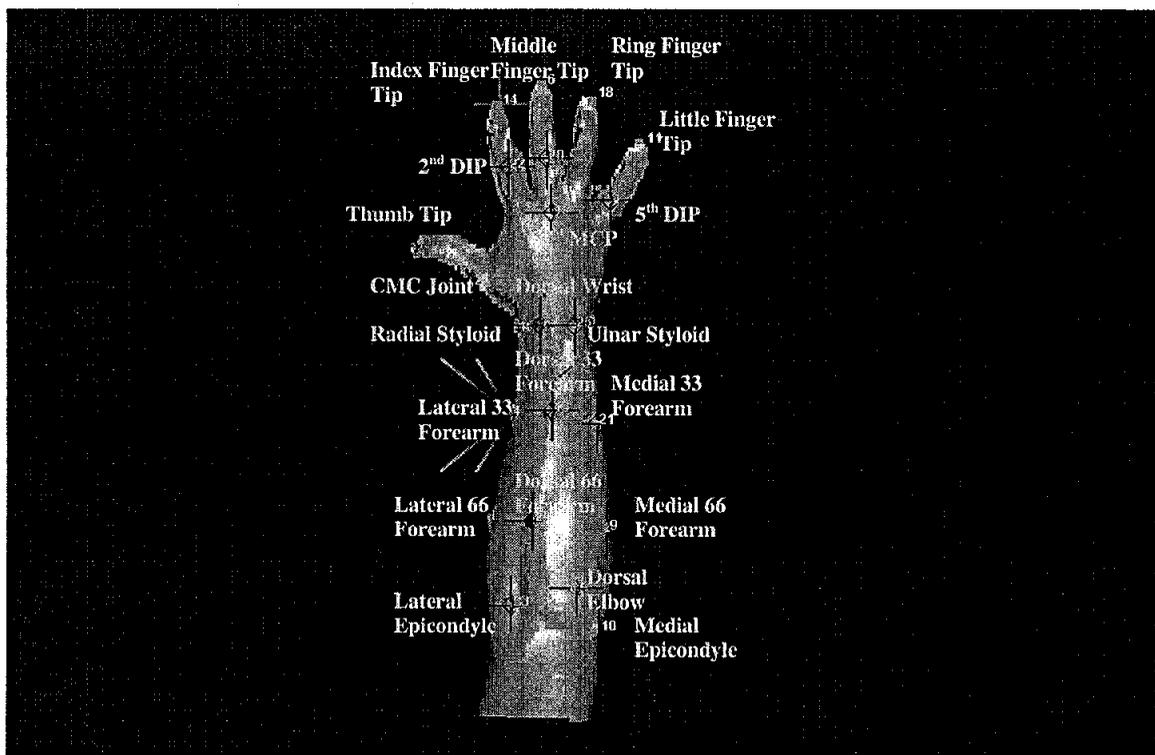


Figure 7. Dorsal View of the Persistent Markers of the FHC in the Measure3D Window.

Feature Name	Feature Coordinates
Distal Observe point	
wrist hand back point	
wrist hand front point	
wrist hand left point	
wrist hand right point	
wrist path left	
wrist path right	
wrist path front	
forearm wrist l	
forearm wrist r	
wrist path R	
max body circumference point	
max body path point front	
max body path point left	
max body path point right	
Lateral 66 Forearm	(0.0021, -0.0161, 0.0463)
Ulnar 33 Forearm	(0.0047, -0.0229, 0.0158)
Thumb Tip	(0.1528, -0.0360, 0.1074)
Dorsal Elbow	(0.1337, 0.0447, 0.0113)
Index Finger Tip	(0.2754, -0.0118, 0.0333)
Middle Finger Tip	(0.1202, -0.0228, 0.0604)
Ring Finger Tip	(0.0795, -0.0315, 0.0533)
Little Finger Tip	(0.2634, 0.0315, 0.0325)
Dorsal Wrist	(0.0441, 0.0326, 0.0152)
Medial Epicondyle	(0.1759, 0.0393, 0.0338)
Lateral Epicondyle	(0.2126, 0.0397, 0.0648)
CMC Joint	(0.1202, -0.0228, 0.0604)
5th DIP	(0.0728, -0.0134, 0.0145)
MCP	(0.1324, 0.0189, 0.0254)
Dorsal Wrist	(0.0441, 0.0326, 0.0152)
Radial Styloid	(0.0005, 0.0029, 0.0230)
2nd DIP	(0.2285, -0.0079, 0.0325)
Dorsal 33 Forearm	(0.0119, 0.0424, 0.0156)
Ring Finger Tip	(0.2820, -0.0040, 0.0425)
Dorsal 66 Forearm	(0.0021, 0.0278, 0.0320)
2nd MCP	(0.1610, 0.0441, 0.0401)
2nd DIP	(0.2213, 0.0324, 0.0324)
Medial 33 Forearm	(0.0011, 0.0427, 0.0304)
Lateral Epicondyle	(0.1542, 0.0142, 0.0375)
Ulnar Styloid	(0.0047, -0.0229, 0.0158)
Medial 66 Forearm	(0.0093, 0.0421, 0.0400)

Figure 8. 3D Coordinates of the Persistent Markers from the Measure Inspector.

The 3D coordinates of the persistent markers were retrieved from the list of feature points by selecting Measure>Inspect Measures in the Measure3D menu (Figure 8). The feature files were saved into a text file and imported into MATLAB.

Similar procedures were taken to scan the upper extremity motion at various example postures. A total of 51 bead markers are used (Figure 9).

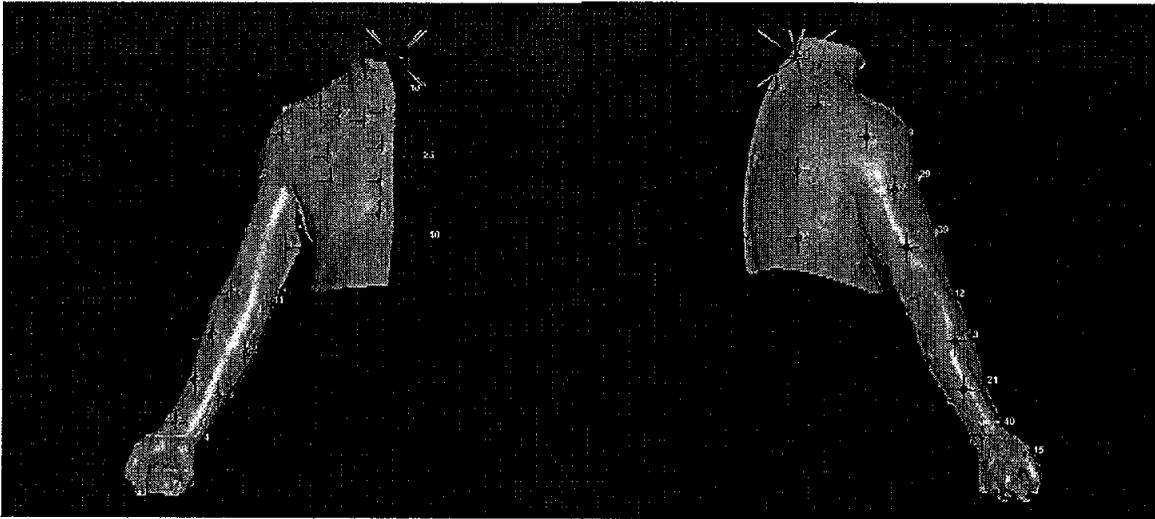


Figure 9. Anterior (left) and Posterior (bottom) Views of the Persistent Markers of the upper extremity in the Measure3D Window.

FUTURE WORKS

- Conducting 3D kinematic analysis using the persistent marker data to estimate the joint angles for each different example postures
- Filling holes and gaps in the scans for surface parameterization and correspondence
- Building posable 3D forearm/hand complex and upper extremity models
- Validating the models with the scans at arbitrary postures to estimate the maximum position errors
- Documenting the results for submitting conference abstracts and/or journal papers

REFERENCES

Logan DL (2002) "A First Course in Finite Element Methods", 3rd Ed, Brooks/Cole, Pacific Grove, CA.